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Plasma potential and fluctuation measurements in the VINETA helicon plasma with a laser-heated emissive probe

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Abstract

We report on the latest development of an emissive probe which is heated by a laser beam. A laser-heated emissive probe has a few advantages like higher electron emissivity, long life-time, good time resolution and no potential drop across the probe tip compared to a conventional dc heated emissive probe. We have used such a probe in the edge region of the VINETA helicon plasma.

1. Introduction

An emissive probe offers the possibility to measure the plasma potential Φ_{pl} directly since its floating potential $V_{fl,em}$ is approximately equal to the plasma potential. Under certain conditions, however, deviations are possible. So on one side, it was often found that $V_{fl,em}$ remains below the value of Φ_{pl} as derived from the cold probe characteristic (the electron saturation current "knee"), in particular in plasmas with electron temperatures in excess of a few eV [1]. This effect was discussed theoretically also in [2] as being due to space charge effects around the floating emissive probe. On the other side, in plasmas with electron temperatures around or below one eV, the floating potential of a strongly emissive probe can even exceed the plasma potential [3].

In particular if plasma potential fluctuations are to be measured, we emphasize that a cold Langmuir probe is of limited use since even in a Maxwellian plasma its floating potential V_{fl} is by a factor of $T_e \ln(I_{es}/I_{is})$ smaller than the plasma potential, where $I_{es,is}$ is the electron and ion saturation current, respectively. Thus, to determine Φ_{pl} by a cold probe via the measurement of V_{fl} , $T_e(r,t)$ has to be known rather precisely (with r being the space coordinate and t the time). Moreover, this value is easily spoilt e.g. by fast electrons. Thus, in any case the floating potential of an emissive probe delivers a more reliable measure of Φ_{pl} than a cold probe.

Conventional emissive probes, consisting of a loop of a refractory metal, heated by an electron current, have drawbacks like (i) short lifetime because the wire melts when heated too strongly (this effect also limits the available emission current), (ii) low time response since the whole heating power supply has to float with the probe when the floating potential is measured, (iii) a potential drop across the wire.

2. Experimental setup and results

The above mentioned disadvantages of a conventional emissive wire probe can be avoided if another means to heat the probe tip is used than an electric current. Since 2004 we have develop several types of emissive probes heated by a focused infrared laser beam [4,5]. Recently, we have developed a radially moveable laser-heated emissive probe to measure the radial profiles of the time-averaged plasma potential and plasma potential fluctuations in the VINETA helicon discharge plasma at relatively high plasma densities ($n_e \cong 10^{19}$ m^{-3}). Fig. 1 shows a schematic of the setup.

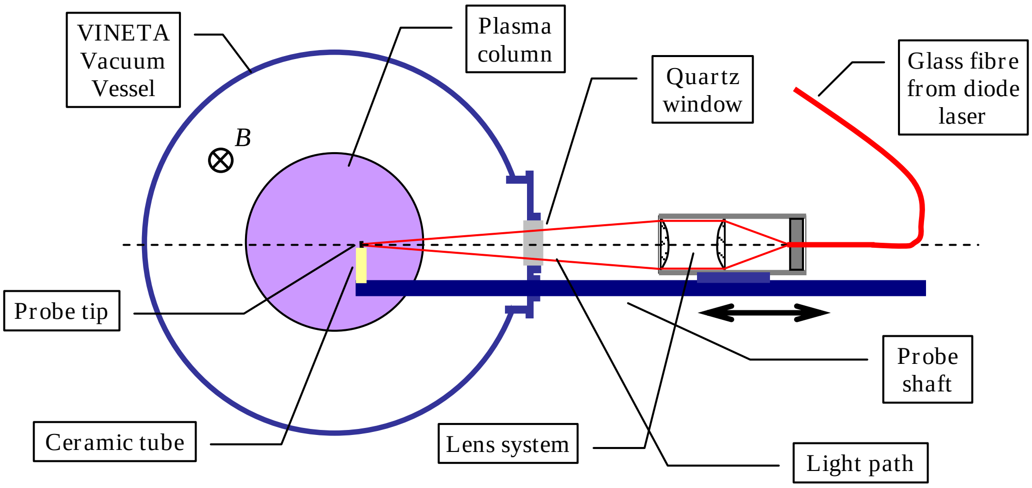

Fig. 1: Schematic of the radially moveable laser-heated emissive probe.

The probe tip consists of a piece of graphite of either cylindrical shape with 1 mm diameter and 3 mm length or a disk of 3 mm diameter and 1 mm thickness. The piece is heated through a quartz window by an infrared diode laser with a wavelength of 808 nm and a steady state power up to 50 W. The laser beam is focused on the probe tip by a lens system of 25 cm focal length mounted on the same radially movable probe shaft. In this way the laser focus lies on the probe tip also when the probe is shifted radially. It turned out that the focal point of the laser light has a diameter of about 2 mm, so in case of the cylindrical probe tip not the entire radiation power is focused on the probe. Without heating the probe acts as a normal cold probe.

The VINETA plasma is produced by a helicon discharge with an RF power of 2 kW creating densities up to about 10^{19} m^{-3} and an electron temperature of about 3 eV [6]. The confining magnetic field is 100 mT and the neutral Ar-pressure is 0,2 Pa. The plasma column radius is around 10 cm and the maximum density is reached in the centre.

The probe with the cylindrical probe tip was first inserted into the centre of the plasma and heated-up. The *IV*-characteristic of the probe was registered by sweeping the probe voltage between –40 and +40 V. Under the assumption that there is no electron drift in the plasma, the plasma potential was also derived from the maximum of the first derivative of the *IV*-characteristic of the cold probe which was benchmarked against the floating potential of the emissive probe.

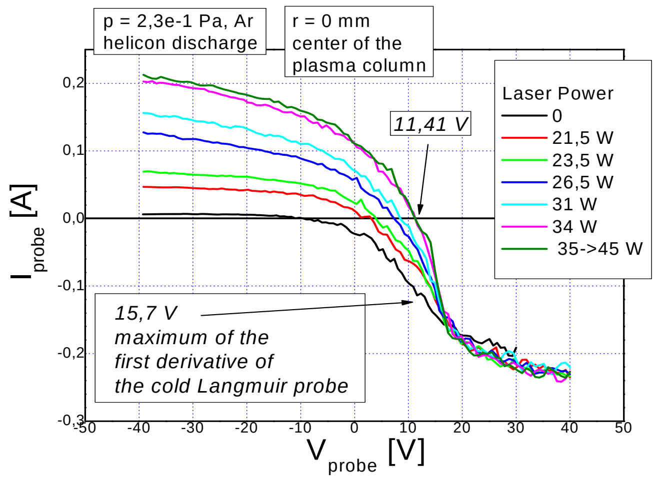

Fig. 2: Current-voltage characteristics of the laser-heated electron-emissive probe in the centre of the VINETA plasma column, showing its working principle. With increasing laser heating power the probe tip reaches sufficient emission so that its floating potential shifts towards the plasma potential. When the emissive probe is hot enough the floating potential is a good approximation of the plasma potential.

Fig. 2 shows that with increasing laser heating power up to 35 W the probe reaches sufficient emission so that the floating potential is shifted towards the plasma potential. Usually it is assumed that in a Maxwellian plasma an emissive probe indicates the most reliable value of the plasma potential when the magnitude of the saturated emission (plus ion saturation) current is equal to that of the plasma electron current, i.e., when the *IV*-characteristic is roughly symmetric. In case of drifting electrons the emission current has to be correspondingly higher. Then the sweeping circuit can be disconnected and the plasma potential can be measured directly.

Fig. 2 shows also that after the laser power reached 35 W the emission current does not increase any further, probably due to heat losses through radiation and probe support conduction. In this case the measured floating potential of the emissive probe is 11,4 V, which value is 4,3 V below the value of 15,7 V, i.e. the plasma potential found from the maximum of the first derivative of the cold probe. Thus the floating potential of the emissive probe is about one T_e smaller than the cold probe value. This is in agreement with earlier findings on the laser-heated probe [4] and on a conventional wire probe in the CASTOR tokamak [1],

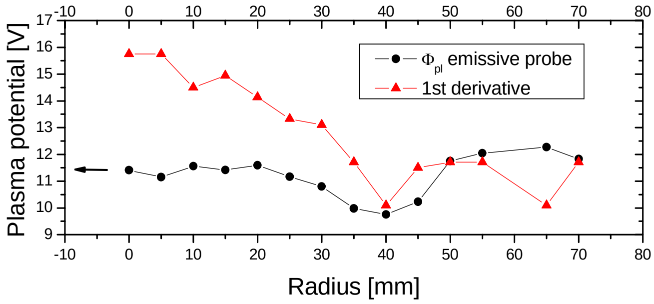

Fig. 3: Radial profiles of the plasma potential profile obtained with the laser-heated electron-emissive probe (black dots) and from the first derivative of the cold probe (red triangles)(left ordinate) and of the ion saturation current (blue asterisks) (right ordinate).

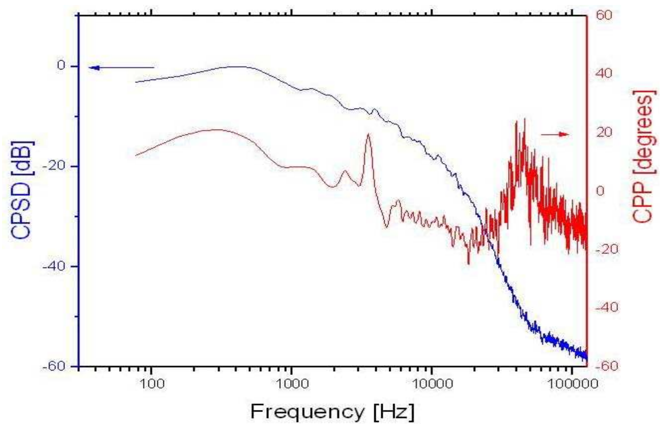

Fig. 4. Cross-power spectral density (CPSD) and corresponding cross-phase spectrum of the plasma and floating potential fluctuations.

and with other theoretical considerations [2]. It is remarkable that, in contrast to earlier findings [4], there is no variation of the electron saturation current with the emission current.

Fig. 3 shows radial profiles of plasma potential measurements with the laser-heated emissive probe and the cold probe (maximum of the first derivative method). The electric field measured with the emissive probe is well reproduced compared to the cold probe. However, we notice that the discrepancy between the value of Φ_{pl} determined from the first derivative of the cold *IV*-characteristic and the floating potential of the emissive probe becomes larger the further we advance into the plasma column.

Figure 4 shows the cross-power spectral density [CPSD] and the corresponding cross-power phase (CPP) spectra between plasma and floating potential fluctuations obtained in a weakly developed drift wave turbulent regime. The CPSD indicates that the spectral energy is concentrated below frequencies of 10 kHz and decays after a 1/*f*-law for higher frequencies. The CPP is between zero and twenty degrees in the low frequency range, due to the electron temperature fluctuations, which have a strong impact on the fluctuation-induced radial particle flux.

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